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***Research Article***

# Determination of Mass Attenuation Coefficients of Different Types of Concretes using Monte Carlo Method

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**Abstract**

Shielding and radiation protection are important subjects for various areas ranging from medical and agricultural sectors to consumer products. As such, it is a branch of science and technology, wherein radiation exposure to the receptor is reduced by shielding. In this study mass attenuation coefficients, $\mu/\rho$ for some concrete with potential applications in nuclear technology and radiation protection as well as medical physics have been calculated using MCNPX (version 2.4.0) at different photon energy levels. Appreciable variations are noted for mass attenuation coefficients of the concrete by the changes in the photon energy. The MCNPX results are compared with available experimental investigations and theoretical XCOM results, and good agreement is being observed. Present study indicates that MCNPX simulation method is suitable method to be used as an alternative method for the investigation of gamma interaction and would very useful materials for different energies for radiation dosimetry, medical and nuclear technology.

**Key words**: Concrete, Dosimeter, Attenuation Coefficient, Gamma, MCNPX

# Farklı Türdeki Betonların Kütle Zayıflatma Katsayılarının Monte Carlo Metodu ile Belirlenmesi

**Öz**

Zırhlanma ve radyasyondan korunma medikal ve tarım sektöründen tüketim ürünlerine kadar oldukça fazla sayıda alan için oldukça önemli bir konu başlığıdır. Bu çalışmada nükleer teknoloji, radyasyondan korunma ve medikal tıp alanında potansiyel kullanıma sahip betonların kütle azaltma katsayılarını, $\mu/\rho$, farklı foton enerjilerinde MCNPX (versiyon 2.6.0) Monte Carlo kodu kullanılarak hesaplanmaktadır. Foton enerjisini değiştirerek betonların kütle azaltma katsayıları için kayda değer farklılıklar kaydedilmiştir. MCNPX sonuçları mevcut deneysel araştırmalar ve teorik XCOM sonuçları ile karşılaştırılmış ve iyi bir uyum gözlenmiştir. Bu çalışma, MCNPX simülasyon yönteminin, gama etkileşiminin araştırılmasında alternatif bir yöntem olarak kullanılacak uygun bir yöntem olduğunu göstermektedir ve radyasyon dozimetresi ve nükleer teknoloji alanında oldukça faydalı materyaller içermektedir.

**Anahtar kelimeler**: Beton, Dozimetre, Kütle Azaltma Katsayısı, Gama, MCNPX

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# 1. Introduction

Radiation protection and shielding is one of the most critical issues in medical, agriculture, industries, and consumer products. As such, it is a branch of science and technology, wherein radiation exposure to the receptor is reduced by shielding. The shielding material is an important factor that determines the effectiveness of radiation protection. Various types of shielding materials are being invented and investigated in detail for the purposes of shielding and dosimetric applications. A Variety of different materials are being used for personal dosimeter for radiation dose measurement. To represent the realistic radiation interaction similar to human body organs, tissue equivalent materials becomes often most used materials in different applications(Hubbell, 1999). For instance, water exhibits adequate suitability as tissue equivalent for radiation interaction and being considered most useful in medical applications for simulation purpose(V. P. Singh & Badiger, 2013). For all types of materials, mass attenuation coefficients (MAC) is the most important parameter to determine the shielding properties of the material as it is the major factor for other interacting parameters (Dong et al., 2019; Vishwanath P. Singh & Badiger, 2013).

In the interaction of photon with the shielding and dosimetry materials, (the transmitted/absorbed/scattered back photon. In order to understand the essence of the interaction of the photon with the dosimetry materials and the quality of the shielding, it is vital to determine MAC. The photon interaction processes (namely photoelectric absorption, Compton scattering and pair production) also dependent upon photon energy and atomic number (Z) of the elements of compound or mixture. Therefore, in addition to MAC, these parameters must be investigated for determining the shielding properties of any materials. This study focusses on the determination of MAC for concretes using Monte Carlo method. Concretes are the high demanding materials in radiation protection field since they are suitable for a variety of dosimetry applications with the mixture of low- as well as high-z elements. In addition to their special quality for shielding application, concretes are valuable for their cost-effectiveness, easy-handling, construction in desired shape and size and decommissioning.

This article uses Monte Carlo simulation for shielding and dosimetric material to investigate the mass attenuation coefficients, which is an often-employed application(AlMateri et al., 2019; Vishwanath P. Singh, Ali, Badiger, & El-Khayatt, 2013; Tekin, Sayyed, et al., 2018). Monte Carlo N-Particle Extended (MCNPX) is an application used for modeling of the interaction of radiation with the materials(Vishwanath P. Singh, Medhat, & Badiger, 2014; Tekin, Altunsoy, Ozturk, Kilicoglu, & Sayyed, 2018). Los Alamos National Laboratory has developed the MCNPX code for simulation of mass attenuation coefficients of the polymers and water. It is a general-purpose radiation code with user-friendly and powerful features like displaying three-dimensional graphics and utilizing extended nuclear cross section libraries (Tekin, Sayyed, Altunsoy, & Manici, 2017). As such, it allows us to track all particles at all energies. Capability of MCNPX code on detection efficiency and using of different experimental can be found by Tekin et al. (Issa, Saddeek, Sayyed, Tekin, & Kilicoglu, 2019; Issa, Tekin, et al., 2019). In addition to MCNPX, the article use the XCOM program, which is software for providing photon cross section data for a single element, compound, or mixture in energy area from 1 keV to 100 GeV(Berger, 2010).

# 2. Materials and Methods

To test the simulation method and provide radiological safety parameters, this work studies MAC for concretes using calculations via MCNPX code. The chemical compositions of these materials are taken from literature (Vijayakumar, Rajasekaran, & Ramamurthy, 2001). Firstly, mass attenuation coefficients of the selected materials were calculated. Later these calculated results are checked against the results derived from XCOM program (which is the theoretical data) (Bashter, 1997) and simulation results (Issa, Tekin, et al., 2019; Vishwanath P. Singh et al., 2013).

The following mixture rule provides theoretically calculated mass attenuation coefficient (μ/ρ) values for the concretes

$$((\mu/\rho)_{polymer} = \sum_{i}^{n} w_i (\mu/\rho)_i) \qquad (1)$$

where $w_i$ is the proportion by weight and $(\mu/\rho)_i$ is mass attenuation coefficient of the ith element by using XCOM (Berger, 2010; Tekin, Kavaz, et al., 2019; Tekin, Kilicoglu, et al., 2019). In compton region, which is the energy region from 30 keV to 100 MeV, the uncertainties in μ/ρ values is about 1% for low-Z ($1<Z<8$). Due correction to experiments for high-Z impurities and departure of Compton cross section from Klein-Nishina theory, the uncertainties increase to 5-10% below the 30 keV energy(V. P. Singh & Badiger, 2013). Note that above 100 MeV photon energy, uncertainties in μ/ρ values may be as high as 5-10%. Uncertainties in photon energy absorption coefficient may be slightly greater values. The gamma sources of photon energies above 5 keV are being used in medical, biological, industrial, radioactive source transportation and other shielding applications. Hence uncertainty in the result may not have any impact for practical applications. The mass attenuation coefficient (μ/ρ) values for the selected materials were computed by the MCNPX simulation code corresponding to the photon energies of 59.5, 279.1, 511, 661.6, 662, 1173.2, 1274.5 and 1332.5 keV. The present results were compared with earlier investigation in addition to both the theoretical and experimental results from derived from XCOM and literature.

Cell definitions, surface definitions, material definition and position of each tools are some of MCNPX simulation parameters. These parameters have been defined in input file according to their properties. Samples takes a cubic geometrical form with the sizes of 10x10x5 cm (height-width-thickness). The figure 1 depicts the total simulation geometry while figure 2 shows the schematic view of MCNPX simulation setup with Pb collimator, investigated dosimeter materials samples, Pb shields for backscattered and unused photons and detection.

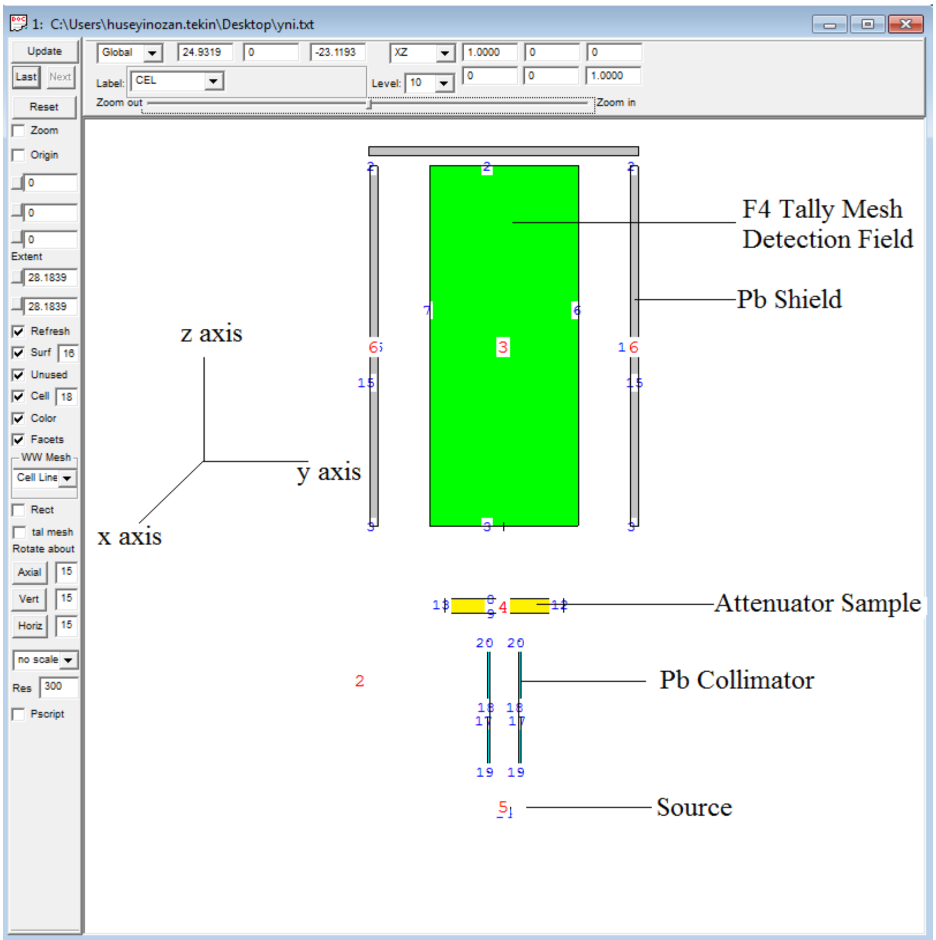


Figure 1: Total simulation geometry

Gamma-ray source, lead (Pb) (density=11,34 g/cm$^3$) collimators and shields, samples and detection area have been defined in cell card, surface card and data card sections of MCNPX input. The basic variables such as CEL, ERG, DIR, POS, and PAR have been defined, respectively. The geometric center of detection area has been considered for location of point source. The source has been defined as a point source at photon energies of 59.5, 279.1, 511, 661.6, 662, 1173.2, 1274.5 and 1332.5 keV. The energy deposition mesh tally (F6) is used for acquiring the absorbed dose amount in detection area. This type of tally in MCNPX scores energy deposition data in which energy deposited per unit volume from all particles is included. MCNPX calculations were completed by using Intel® Core ™ i7 CPU 2.80 GHz computer hardware. The error rate has been observed less than %1 in output file. The same simulation parameters have been applied for all samples. In each simulation, density of dosimeter materials has been defined in input file.

Table 1: Mass attenuation coefficient concrete shielding materials using MCNPX and comparison with XCOM, Expt, Gent4 and MCNP

| Energy (MeV) | Ordinary Concrete | | | | | Energy (MeV) | Hematite-serpentine | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | MCNPX | Xcom | Expri. | Geant4 | MCNP | | MCNPX | Xcom | Exp. | Geant4 | MCNP |
| 1.5 | 5.04E-02 | 5.19E-02 | 7.13E-02 | 6.12E-02 | 5.15E-02 | 1.5 | 4.96E-02 | 5.15E-02 | 4.96E-02 | 5.05E-02 | 5.29E-02 |
| 2 | 4.19E-02 | 4.47E-02 | 5.04E-02 | 4.88E-02 | 4.44E-02 | 2 | 4.19E-02 | 4.46E-02 | 4.20E-02 | 4.32E-02 | 4.70E-02 |
| 3 | 3.27E-02 | 3.64E-02 | 4.30E-02 | 3.89E-02 | 3.62E-02 | 3 | 3.36E-02 | 3.67E-02 | 3.72E-02 | 3.81E-02 | 3.85E-02 |
| 4 | 2.73E-02 | 3.17E-02 | 3.78E-02 | 3.56E-02 | 3.15E-02 | 4 | 2.74E-02 | 3.24E-02 | 3.52E-02 | 3.30E-02 | 3.44E-02 |
| 5 | 2.47E-02 | 2.88E-02 | 3.39E-02 | 2.68E-02 | 2.86E-02 | 5 | 2.44E-02 | 2.97E-02 | 3.20E-02 | 3.11E-02 | 3.04E-02 |
| 6 | 2.17E-02 | 2.68E-02 | 3.39E-02 | 3.20E-02 | 2.66E-02 | 6 | 2.27E-02 | 2.80E-02 | 3.28E-02 | 3.12E-02 | 2.76E-02 |
| Energy (MeV) | ilmenite-limonite | | | | | Energy (MeV) | Basalt-magnetite | | | | |
| | MCNPX | Xcom | Exp. | Geant4 | MCNP | | MCNPX | Xcom | Exp. | Geant4 | MCNP |
| 1.5 | 4.84E-02 | 5.05E-02 | 5.48E-02 | 5.13E-02 | 5.17E-02 | 1.5 | 4.97E-02 | 5.14E-02 | 4.56E-02 | 4.98E-02 | 5.27E-02 |
| 2 | 4.07E-02 | 4.37E-02 | 4.07E-02 | 4.23E-02 | 4.36E-02 | 2 | 4.16E-02 | 4.44E-02 | 3.61E-02 | 4.01E-02 | 4.47E-02 |
| 3 | 3.27E-02 | 3.63E-02 | 3.48E-02 | 3.54E-02 | 3.74E-02 | 3 | 3.37E-02 | 3.65E-02 | 3.11E-02 | 3.46E-02 | 3.80E-02 |
| 4 | 2.74E-02 | 3.23E-02 | 3.17E-02 | 3.11E-02 | 3.34E-02 | 4 | 2.77E-02 | 3.23E-02 | 2.69E-02 | 3.01E-02 | 3.34E-02 |
| 5 | 2.47E-02 | 2.99E-02 | 2.97E-02 | 3.01E-02 | 3.03E-02 | 5 | 2.44E-02 | 2.96E-02 | 2.79E-02 | 2.88E-02 | 3.06E-02 |
| 6 | 2.27E-02 | 2.84E-02 | 2.97E-02 | 3.00E-02 | 2.83E-02 | 6 | 2.29E-02 | 2.79E-02 | | 2.52E-02 | 2.74E-02 |
| Energy (MeV) | ilmenite | | | | | Energy (MeV) | Steel-scrap | | | | |
| | MCNPX | Xcom | Exp. | Geant4 | MCNP | | MCNPX | Xcom | Exp. | Geant4 | MCNP |
| 1.5 | 4.87E-02 | 5.03E-02 | 5.71E-02 | 5.16E-02 | 5.30E-02 | 1.5 | 4.96E-02 | 5.03E-02 | 4.90E-02 | 5.05E-02 | 5.25E-02 |
| 2 | 4.12E-02 | 4.36E-02 | 4.39E-02 | 4.30E-02 | 4.37E-02 | 2 | 4.12E-02 | 4.37E-02 | 5.20E-02 | 4.81E-02 | 4.42E-02 |
| 3 | 3.43E-02 | 3.62E-02 | 3.67E-02 | 3.60E-02 | 3.72E-02 | 3 | 3.36E-02 | 3.65E-02 | 4.48E-02 | 4.04E-02 | 3.81E-02 |
| 4 | 2.89E-02 | 3.22E-02 | 3.28E-02 | 3.21E-02 | 3.24E-02 | 4 | 2.98E-02 | 3.28E-02 | 3.95E-02 | 3.68E-02 | 3.29E-02 |
| 5 | 2.49E-02 | 2.98E-02 | 3.20E-02 | 3.03E-02 | 3.13E-02 | 5 | 2.63E-02 | 3.06E-02 | 4.30E-02 | 4.04E-02 | 3.08E-02 |
| 6 | 2.36E-02 | 2.83E-02 | | 2.91E-02 | 2.83E-02 | 6 | 2.48E-02 | 2.92E-02 | | 2.81E-02 | 2.92E-02 |
| | MCNPX | Xcom | Exp. | Geant4 | MCNP | | | | | | |
| 1.5 | 4.98E-02 | 4.98E-02 | 4.31E-02 | 4.65E-02 | 5.18E-02 | | | | | | |
| 2 | 4.09E-02 | 4.34E-02 | 3.97E-02 | 4.02E-02 | 4.23E-02 | | | | | | |
| 3 | 3.29E-02 | 3.64E-02 | 3.60E-02 | 3.71E-02 | 3.63E-02 | | | | | | |
| 4 | 2.88E-02 | 3.29E-02 | 3.52E-02 | 3.30E-02 | 3.32E-02 | | | | | | |
| 5 | 2.56E-02 | 3.09E-02 | 3.41E-02 | 3.20E-02 | 3.20E-02 | | | | | | |
| 6 | 2.38E-02 | 2.97E-02 | | 2.88E-02 | 2.90E-02 | | | | | | |

Table 2: Mass attenuation coefficient dosimetric materials using MCNPX and comparison with XCOM, Expt, Gent4, and MCNP

| Energy (MeV) | LiF | | | | Energy (MeV) | $C_4H_6BaO_4$ | | | |
|---|---|---|---|---|---|---|---|---|---|
| | MCNPX | XCOM | Expt | Geant4 | | MCNPX | XCOM | Expt | Geant4 |
| 0.2792 | 7.31E-02 | 1.02E-01 | 1.01E-01 | 9.70E-02 | 0.2792 | 1.76E-01 | 1.68E-01 | 1.65E-01 | 1.61E-01 |
| 0.3201 | 6.98E-02 | 9.66E-02 | 9.50E-02 | 9.00E-02 | 0.3201 | 1.41E-01 | 1.43E-01 | 1.41E-01 | 1.33E-01 |
| 0.514 | 5.70E-02 | 7.98E-02 | 8.01E-02 | 7.10E-02 | 0.514 | 7.76E-02 | 9.38E-02 | 9.28E-02 | 8.80E-02 |
| 0.6616 | 4.97E-02 | 7.15E-02 | 7.11E-02 | 6.80E-02 | 0.6616 | 6.05E-02 | 7.92E-02 | 7.91E-02 | 7.40E-02 |
| 1.115 | 3.63E-02 | 5.57E-02 | 5.55E-02 | 5.20E-02 | 1.115 | 3.96E-02 | 5.82E-02 | 5.83E-02 | 5.50E-02 |
| 1.173 | 3.51E-02 | 5.45E-02 | 5.37E-02 | 5.10E-02 | 1.173 | 3.80E-02 | 5.68E-02 | 5.71E-02 | 5.10E-02 |
| 1.333 | 3.22E-02 | 5.11E-02 | 5.06E-02 | 4.80E-02 | 1.333 | 3.44E-02 | 5.31E-02 | 5.29E-02 | 4.90E-02 |
| Energy (MeV) | $CdSO_4$ | | | | Energy (MeV) | $SrSO_4$ | | | |
| | MCNPX | XCOM | Expt | Geant4 | | MCNPX | XCOM | Expt | Geant4 |
| 0.2792 | 1.42E-01 | 1.45E-01 | 1.43E-01 | 1.42E-01 | 0.2792 | 1.04E-01 | 1.22E-01 | 1.21E-01 | 1.23E-01 |
| 0.3201 | 1.17E-01 | 1.26E-01 | 1.25E-01 | 1.20E-01 | 0.3201 | 9.18E-02 | 1.11E-01 | 1.10E-01 | 1.08E-01 |
| 0.514 | 7.13E-02 | 8.86E-02 | 8.72E-02 | 8.10E-02 | 0.514 | 6.37E-02 | 8.48E-02 | 8.46E-02 | 8.00E-02 |
| 0.6616 | 5.82E-02 | 7.63E-02 | 7.60E-02 | 7.10E-02 | 0.6616 | 5.39E-02 | 7.46E-02 | 7.41E-02 | 7.50E-02 |
| 1.115 | 3.96E-02 | 5.72E-02 | 5.72E-02 | 5.00E-02 | 1.115 | 3.79E-02 | 5.71E-02 | 5.73E-02 | 5.10E-02 |
| 1.173 | 3.80E-02 | 5.58E-02 | 5.63E-02 | 5.10E-02 | 1.173 | 3.65E-02 | 5.59E-02 | 5.61E-02 | 5.00E-02 |
| 1.333 | 3.46E-02 | 5.22E-02 | 5.24E-02 | 5.30E-02 | 1.333 | 3.34E-02 | 5.23E-02 | 5.25E-02 | 5.40E-02 |
| Energy (MeV) | $CaSO_4$ | | | | Energy (MeV) | $CaCO_3$ | | | |
| | MCNPX | XCOM | Expt | Geant4 | | MCNPX | XCOM | Expt | Geant4 |
| 0.2792 | 8.50E-02 | 1.12E-01 | 1.12E-01 | 1.09E-01 | 0.2792 | 8.53E-02 | 1.12E-01 | 1.11E-01 | 1.01E-01 |
| 0.3201 | 7.99E-02 | 1.06E-01 | 1.05E-01 | 1.04E-01 | 0.3201 | 7.98E-02 | 1.06E-01 | 1.04E-01 | 1.00E-01 |
| 0.514 | 6.30E-02 | 8.67E-02 | 8.62E-02 | 8.10E-02 | 0.514 | 6.28E-02 | 8.67E-02 | 8.59E-02 | 8.40E-02 |
| 0.6616 | 5.50E-02 | 7.75E-02 | 7.77E-02 | 7.30E-02 | 0.6616 | 5.48E-02 | 7.75E-02 | 7.72E-02 | 7.10E-02 |
| 1.115 | 3.97E-02 | 6.03E-02 | 6.05E-02 | 6.50E-02 | 1.115 | 3.95E-02 | 6.03E-02 | 6.05E-02 | 6.30E-02 |
| 1.173 | 3.83E-02 | 5.90E-02 | 5.91E-02 | 5.30E-02 | 1.173 | 3.81E-02 | 5.90E-02 | 5.91E-02 | 5.90E-02 |
| 1.333 | 3.50E-02 | 5.52E-02 | 5.53E-02 | 5.80E-02 | 1.333 | 3.49E-02 | 5.52E-02 | 5.54E-02 | 5.10E-02 |
| Energy (MeV) | $BaSO_4$ | | | | Energy (MeV) | $3CdSO_4.8H_2O$ | | | |
| | MCNPX | XCOM | Expt | Geant4 | | MCNPX | XCOM | Expt | Geant4 |
| 0.2792 | 1.78E-01 | 1.71E-01 | 1.68E-01 | 1.76E-01 | 0.2792 | 1.37E-01 | 1.40E-01 | 1.38E-01 | 1.29E-01 |
| 0.3201 | 1.41E-01 | 1.44E-01 | 1.42E-01 | 1.49E-01 | 0.3201 | 1.15E-01 | 1.24E-01 | 1.23E-01 | 1.13E-01 |
| 0.514 | 7.75E-02 | 9.24E-02 | 9.00E-02 | 9.30E-02 | 0.514 | 7.07E-02 | 9.00E-02 | 8.90E-02 | 9.10E-02 |
| 0.6616 | 6.12E-02 | 7.75E-02 | 7.75E-02 | 7.20E-02 | 0.6616 | 5.76E-02 | 7.80E-02 | 7.79E-02 | 7.10E-02 |
| 1.115 | 4.00E-02 | 5.65E-02 | 5.64E-02 | 5.10E-02 | 1.115 | 3.93E-02 | 5.90E-02 | 5.91E-02 | 5.00E-02 |
| 1.173 | 3.86E-02 | 5.52E-02 | 5.54E-02 | 5.10E-02 | 1.173 | 3.78E-02 | 5.76E-02 | 5.81E-02 | 5.20E-02 |
| 1.333 | 3.46E-02 | 5.15E-02 | 5.16E-02 | 5.40E-02 | 1.333 | 3.46E-02 | 5.39E-02 | 5.37E-02 | 4.80E-02 |
| Energy (MeV) | $CaSO_4.2H_2O$ | | | | Energy (MeV) | Perspex | | | |
| | MCNPX | XCOM | Expt | Geant4 | | MCNPX | XCOM | Expt | Geant4 |
| 0.2792 | 8.48E-02 | 1.14E-01 | 1.13E-01 | 1.08E-01 | 0.2792 | 8.42E-02 | 1.18E-01 | -- | 1.48E-01 |
| 0.3201 | 7.97E-02 | 1.08E-01 | 1.07E-01 | 1.00E-01 | 0.3201 | 7.99E-02 | 1.12E-01 | -- | 1.44E-01 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0.514 | 6.30E-02 | 8.86E-02 | 8.84E-02 | 8.90E-02 | 0.514 | 6.42E-02 | 9.30E-02 | -- | 9.78E-02 |
| 0.6616 | 5.50E-02 | 7.92E-02 | 8.33E-02 | 7.60E-02 | 0.6616 | 5.62E-02 | 8.33E-02 | -- | 8.26E-02 |
| 1.115 | 3.97E-02 | 6.16E-02 | 6.19E-02 | 6.90E-02 | 1.115 | 4.06E-02 | 6.50E-02 | -- | 7.19E-02 |
| 1.173 | 3.84E-02 | 6.03E-02 | 6.05E-02 | 6.20E-02 | 1.173 | 3.99E-02 | 6.36E-02 | -- | 7.23E-02 |
| 1.333 | 3.51E-02 | 5.65E-02 | 5.62E-02 | 5.40E-02 | 1.333 | 3.61E-02 | 5.95E-02 | -- | 6.02E-02 |

| Energy (MeV) | Alanine | | | | Energy (MeV) | Bakelite | | | |
|---|---|---|---|---|---|---|---|---|---|
| | MCNPX | XCOM | Expt | Geant4 | | MCNPX | XCOM | Expt | Geant4 |
| 0.2792 | 8.28E-02 | 1.18E-01 | -- | 1.62E-01 | 0.2792 | 8.32E-02 | 1.16E-01 | -- | 1.41E-01 |
| 0.3201 | 7.91E-02 | 1.12E-01 | -- | 1.44E-01 | 0.3201 | 7.90E-02 | 1.10E-01 | -- | 1.41E-01 |
| 0.514 | 6.38E-02 | 9.29E-02 | -- | 1.07E-01 | 0.514 | 6.38E-02 | 9.10E-02 | -- | 1.04E-01 |
| 0.6616 | 5.61E-02 | 8.32E-02 | -- | 8.37E-02 | 0.6616 | 5.59E-02 | 8.15E-02 | -- | 8.07E-02 |
| 1.115 | 4.04E-02 | 6.49E-02 | -- | 5.64E-02 | 1.115 | 4.03E-02 | 6.36E-02 | -- | 6.23E-02 |
| 1.173 | 3.85E-02 | 6.35E-02 | -- | 6.93E-02 | 1.173 | 3.89E-02 | 6.22E-02 | -- | 7.10E-02 |
| 1.333 | 3.56E-02 | 5.94E-02 | -- | 5.92E-02 | 1.333 | 3.56E-02 | 5.82E-02 | -- | 5.84E-02 |

# 3. Results and Discussion

The mass attenuation coefficient (μ/ρ) values of the concretes at the photon energy ranging from 1 keV to 100 GeV are listed in the Figure1. The μ/ρ values of the concretes greatly vary between different energy regions. In low energy region, the variation is quite wide. It is simply occurring due to photoelectric effect and it sharply increases and decreases along with the changes in the energy levels. This is natural since the interaction between cross-section is dependent upon photon energy and atomic number as $Z^{4-5}$. However, Compton scattering becomes dominant incident in the medium energy region as the interaction between cross-section is independent of photon energy while largely depend upon atomic number. Due to the dependency of interaction cross-section as $Z^2$, the variation of μ/ρ values is low in high energy range. The μ/ρ values for few selected energies were computed using MCNPX, compared with XCOM and that comparison is given in Table 2. To note further, the μ/ρ values derived from MCNPX are also comparable to the values of which are derived from NIST using the XCOM program. From that comparison, it is concluded that the MCNPX is capable of simulation for radiation interaction.

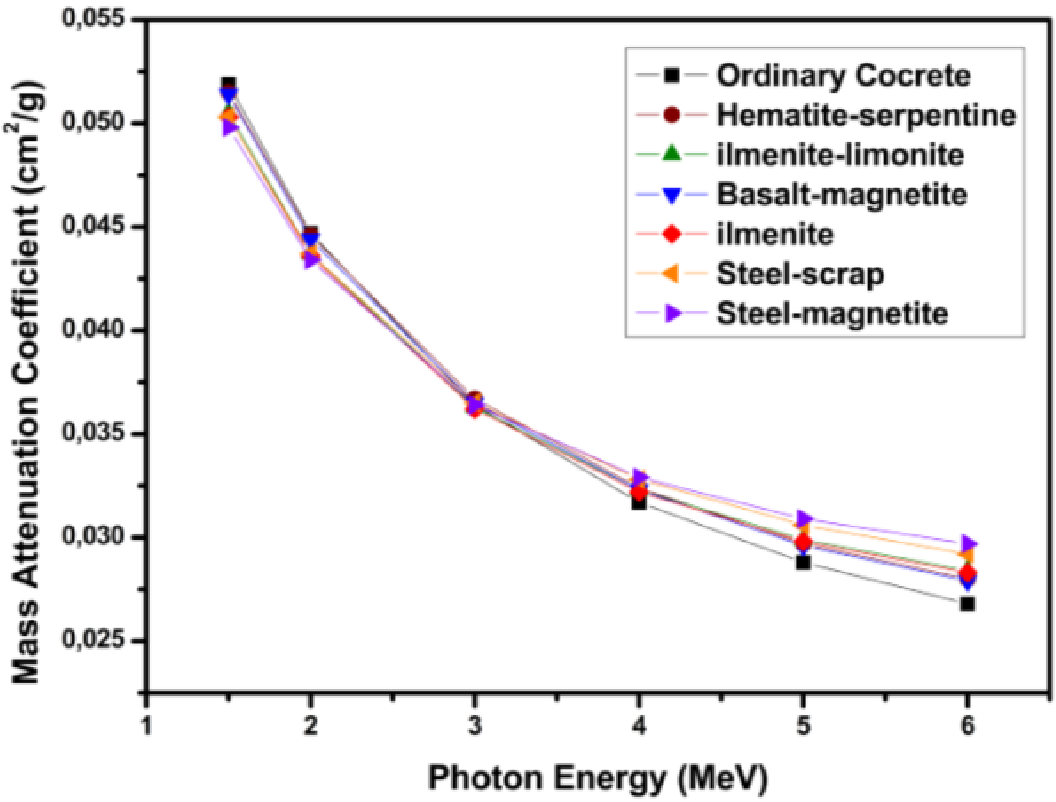


Figure 2: MAC for concretes

The simulated MCNPX, theoretical XCOM, other simulations (Geant4 and MCNP) along with possible experimental results of mass attenuation coefficient (μ/ρ) values for different photon energies are given in Table 1-2. In general, it was found that the μ/ρ values for the concretes and dosimetric materials were very close to theoretical XCOM data, experimental results and other simulations. The slightly higher deviation in results is noted in the present investigation as compared with previous simulations. The possibility for deviation in the results may be the cross section files or computer features. The μ/ρ values calculated by MCNPX for dosimetric materials containing barium ($BaSO_4$ and $C_4H_4BaO_4$) were found to be slightly higher than the remaining results for all the selected photon energies. The discrepancies in the μ/ρ values in present simulation and previous investigations could be due to more precise arrangement for high-atomic number element in the experimental set-up. However, at intermediate and high energies the MCNPX results were found in good agreement with theoretical XCOM data, experiment results and other simulation results. The μ/ρ values for Bakelite and concrete using MCNPX and Fluka (Demir et al., 2013) were also found comparable. It can be concluded that mass attenuation coefficients for compound or composite materials having low-as well as high-atomic number elements for low- to high-energy of photons are found comparable with the experiment and GEANT-4, MCNP and Fluka simulation codes (Vishwanath P. Singh et al., 2014).

# 4. Conclusion

The MCNPX simulated mass attenuation coefficients for the concretes and dosimeters were found to be comparable with the theoretical XCOM values and experimental data. It can be concluded that mass attenuation coefficients for compound or composite materials having low-as well as high- atomic number elements for low- to high-energy of photons are found comparable with the experiment and GEANT-4, MCNP and Fluka simulation codes. The present geometry can be used as standard geometry for MCNPX simulation for low- as well as high-atomic number element materials. The present study would very useful materials for different energies for radiation dosimetry, medical and nuclear technology.

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